DOCUMENT RESUME

ED 390 714 SE 057 694

AUTHOR	Beliveau, Victoria
TITLE	Guide to School Greenhouses: Growing Ideas.
INSTITUTION	National Gardening Association, Burlington, VT.
SPONS AGENCY	National Science Foundation, Washington, D.C.
REPORT NO	ISBN-0-915873-37-0
PUB DATE	95
NOTE	29p.
AVAILABLE FROM	National Gardening Association, 180 Flynn Avenue, Burlington, VT 05401.
PUB TYPE	Guides - Classroom Use - Teaching Guides (For Teacher) (052)
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	Botany; Elementary Education; *Greenhouses; *Hands on Science; *Nurseries (Horticulture); *Plant Growth; *Science Activities

ABSTRACT

This booklet is part of the Growing Ideas series for educators which supports teachers by enabling them to expand their own skills as they help students use plants and gardens as contexts for developing a deeper, richer understanding of the world around them. This booklet, on school greenhouses, gives an overview of key issues relevant to educators planning to run or currently running a school greenhouse program. It covers operational and horticultural topics with an emphasis on how to actively involve students as investigators and participants. Chapters include: "Thinking about a Greenhouse?," "Setting Up the Space," "Maintaining Proper Conditions," "Greenhouse Gardening," "Tackling Pests and Diseases," and "Nurturing Learners." The booklet also contains a list of resources and supplies, including organizations, books, equipment companies, and beneficial insects. (MKR)

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Guide to School Greenhouses

National Gardening Association's
GrowLab

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SE053044

Published by
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Burlington, Vermont 05401

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Printed in the United States of America.

ISBN 0-915873-37-0

1st Printing

The *Growing Ideas* series is an extension of the National Gardening Association's National Science Foundation-funded GrowLab garden-based science program. *Growing Ideas* booklets are designed to help teachers use plants and gardens to engage students in thinking and acting like scientists and to develop a deeper, richer understanding of the world around them.

We would like to thank Colleen Armstrong, Charlie Nardozzi, Becky Young, and Scott Dexter for their input and review of this material. Our sincere thanks also go to the educators whose greenhouse experiences have informed this booklet. Many of their suggestions appear throughout its pages.

Table of Contents

Why School Greenhouses? 3

Thinking About a Greenhouse?

Questions and Challenges 4

Greenhouse Styles 4

Cost 6

Location 6

Glazing 7

Setting Up the Space 8

Maintaining Proper Conditions

The Greenhouse Environment 9

Greenhouse Climates 9

Light 10

Temperature 11

Greenhouse Gardening 13

A Growing Calendar 13

Planting Options 13

Growing Media 14

Starting from Seed 15

Starting from Cuttings 16

Watering 17

Humidity 18

Tackling Pests and Diseases 18

Prevention: The Best Medicine 18

Greenhouse Pests 101 19

Nurturing Learners 20

Developing Objectives 20

Greenhouse Activities for Growing Minds 21

Resources and Supplies 23

More Growing Resources from the National Gardening Association 24

PREFACE

At a time when our education system is under fire — from parents, politicians, special interest groups, and national educational reformers — it is reassuring to know that some truths about learning endure. What is true is that children enjoy thinking, raising questions, manipulating, sorting, testing, and investigating for themselves. What can be more engaging than nurturing and exploring living things? *Growing Ideas*, the National Gardening Association's series for educators, supports teachers by enabling them to expand their own skills as they help students use plants and gardens as contexts for developing a deeper, richer understanding of the world around them. This volume's focus is on school greenhouses.

NGA's Guide to School Greenhouses does not profess to be a complete "how-to" but, rather, a basic overview of key issues relevant to educators planning to run or currently running a school greenhouse program. It covers operational and horticultural topics, with an emphasis on how to actively involve students as investigators and participants. It is intended to be used in conjunction with NGA's other indoor gardening resource books, *GrowLab: A Complete Guide to Gardening in the Classroom* and *GrowLab: Activities for Growing Minds*.

You may already use a school greenhouse and want to make it an even more useful learning tool; have one that has fallen into disuse that you'd like to renew; or be contemplating building or purchasing a greenhouse. Each of these circumstances provides a unique set of challenges, many of which are highlighted in this guide.

"I can't overemphasize the positive benefits I've seen. The greenhouse-environment-as-a-classroom concept was a completely new learning experience for my daughter. She positively flourished and now has a good understanding of the complexity and importance of plant life to our ecosystems."

— Parent, Essex, VT

This* Growing Ideas *school greenhouse kit is available from the National Gardening Association.
See page 24 for more information.

WHY SCHOOL GREENHOUSES?

Integrating a greenhouse into the school year and curriculum takes time and planning. With all of the demands you already face as an educator, why take on a greenhouse project?

Because greenhouses are living laboratories. When students step into a greenhouse, it is clear that the classroom walls have disappeared . . . but the opportunities for investigating and learning have begun. With so many senses stimulated — by colors, textures, patterns, fragrances, earthy smells — students can't help but become curious observers and inquirers. A greenhouse is an ecological island separated from its surroundings, experiencing its own seasonal and annual cycles, and featuring fascinating and complex interrelationships. Your pupils can study and adjust the climate while exploring plants' and other organisms' responses to it. "A greenhouse can be a unique part of the world," says retired school district horticulturist Bill Horton of Detroit, MI. "It's an almost magical place that features mysteries and surprises, along with energy and quiet beauty. I sometimes find it a calming context for involving students in quiet reading, reflecting, writing, or drawing."

"In the cities, we've lost our knowledge and appreciation of how the food cycle and other life cycles work," says Lori Landry, who works with special needs children in Vermont schools. "A greenhouse is an inviting environment that can help students understand key life science concepts and in which children can delight in the unexpected." In addition to raising a wide range of plants, Lori has helped students raise and investigate butterflies and praying mantises right in school greenhouses.

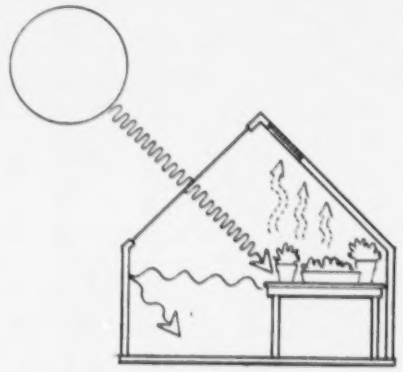
Even in a small greenhouse, students learn about plants as whole systems. They can move beyond the pretty plant in the pot to discover plant roots and soil microbes associated with the roots. They can experiment with water movement, pollination, and nutrition, and explore relationships between plants and insects. They can try to simulate different habitats, and understand how physical factors and climate relate to plant type and growth.

You can use a greenhouse merely to extend your outdoor growing season or as a centerpiece for studies across the curriculum. Raising plants and conducting community or schoolwide plant sales can enrich students' understanding of economics as well as basic plant needs. Raising plants from different regions and cultures can bring geography, history, and even multicultural studies to life. Greenhouses provide an ideal setting for ecology lessons on adaptations, habitats, plant communities, species preservation, and food webs. Students can investigate the systems scientists have developed to group living things. Physics explorations of light, heat, shadows, and water cycles take on immediate relevance in a school greenhouse.

Finally, integrating a greenhouse as a learning environment offers boundless opportunities for promoting student responsibility, and helps develop confidence and pride as students display and share the fruits (and vegetables and flowers) of their labors!

The Greenhouse Effect

All greenhouses operate on the same basic principle. Radiant (light) energy from the sun can pass through transparent and semi-transparent materials. When the light arrives inside a closed space, it is absorbed by the surfaces within, then radiated again as thermal (heat) energy. The heat energy is less able to pass through the transparent or semi-transparent materials, so the heat is trapped inside. Anyone who has entered a car parked in a sunny location knows what that trapped heat feels like! This heat energy warms the air, enabling plant growth. As a simple but powerful exploration of this phenomenon, invite students to place a thermometer inside a clear, covered glass jar in the sun. Place a second thermometer next to the jar. After half an hour, compare the two temperatures. Your students may be surprised at the difference between the two readings.



Thinking About a Greenhouse?

Questions and Challenges

If your school is considering building, purchasing, or resurrecting a greenhouse, there are a number of factors to consider and questions to ask long before you begin designing planting projects. This section highlights some of those factors. References listed on page 23 provide in-depth information that can help you make decisions.

Before investing in a school greenhouse, teachers and students should become comfortable raising plants in the classroom, whether in GrowLabs, in other types of fluorescent light units, or on windowsills. There are enough additional challenges involved in greenhouse growing, to make it important to first have a basic level of comfort with growing things.

Your decision about the type of greenhouse to choose will be influenced by how you plan to use it. You may, for instance, be mainly looking for an opportunity to raise spring seedlings for a plant sale or school garden. Or you may want to use the greenhouse as a year-round living laboratory that serves as a centerpiece for your plant science curriculum. What types of plants do you want to grow? Banana trees and garden seedlings require very different setups. Your local climate and the budget you have for constructing or refurbishing and maintaining a greenhouse are other key factors affecting your choice.

Consider conducting a planning meeting with administrators, custodians, teachers, and others in your school to answer some of the questions in the box above. Then talk with greenhouse builders and people at nurseries, botanical gardens, and other schools that have greenhouses to gather information specific to your unique situation.

Planning Homework Questions

Whether you're refurbishing an old structure or acquiring a new greenhouse, try to gather key potential participants in your school to answer the following questions early in the planning process:

- What are our goals in initiating a greenhouse program?
- How do we envision using a greenhouse? (e.g., for student plant experiments? for teaching plant science concepts? for extending the outdoor gardening season? as a context for a plant business?)
- How many students would we like to use the greenhouse at one time? Which grades will be involved?
- How do we want to integrate it into the curriculum at different grade levels and in different subject areas?
- During which seasons do we hope to use the greenhouse?
- Who are resource people in the school with experience in indoor and/or greenhouse gardening? In the community? How much time can they commit to the project?
- Who will be responsible for the technical aspects of greenhouse operation?
- How committed are the school district, board, faculty, and staff to the greenhouse project?
- Might vandalism be a problem? How can we guard against it?
- Where might we get funding?

(Green) Thumb-Nail History

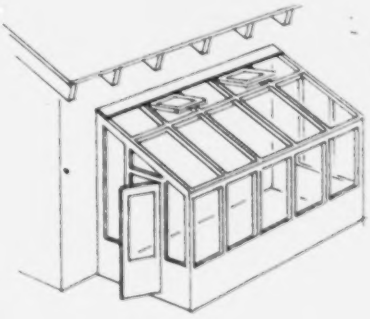
The earliest recorded greenhouse was built about 30 A.D. for the Roman emperor Tiberius. Because glass had not been invented, the greenhouse (called a *specularium*, from the Latin for "to look") was made of small clear pieces of mica, a naturally occurring mineral. It was quite time-consuming to build and was devoted to growing delicate citrus fruits. For the next 1,500 years or so, the few wealthy people who did own greenhouses raised exotic fruits and flowers. From the 1800s on, developments in technology provided new materials at lower cost and higher efficiency. What more can your students learn about the history of greenhouses?

Greenhouse Styles

Greenhouses may be either freestanding or attached to a building, and come in a variety of styles. Most commercial greenhouses are freestanding structures built in exposed areas with plenty of sunlight (maximum sunlight is the most important factor for efficient plant growth). A freestanding greenhouse could be a permanent structure, complete with a foundation and automated controls, or a simpler (and much less

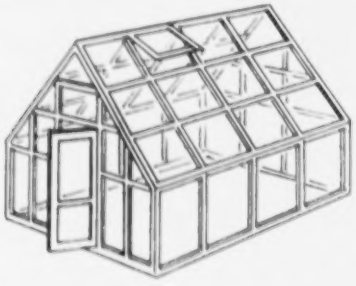
expensive) hoop-type structure that helps you start growing garden plants earlier in the spring and extend the season for some vegetables into the fall. Free-standing greenhouses do have some drawbacks: In a school setting, they may be less accessible to classrooms and to sources of electricity and water, and heating costs tend to be higher. Attached greenhouses are generally more accessible, cost less to heat, and are closer to water and other services; however, they are typically more costly to construct and receive less total light than free-standing structures.

The following drawings illustrate some common greenhouse styles. Reference books and suppliers listed on page 23 provide detailed descriptions of different options.

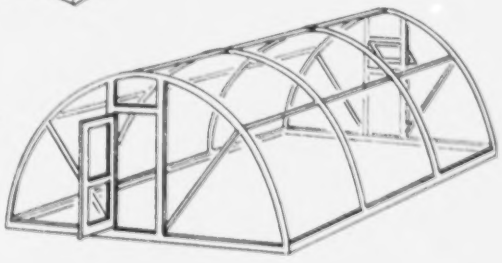


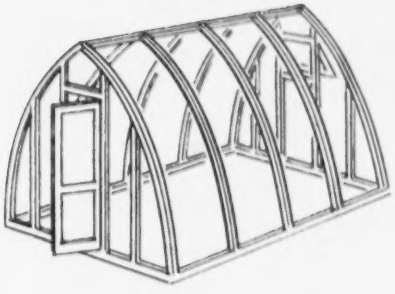
Attached (lean-to) greenhouse

Basic freestanding greenhouse

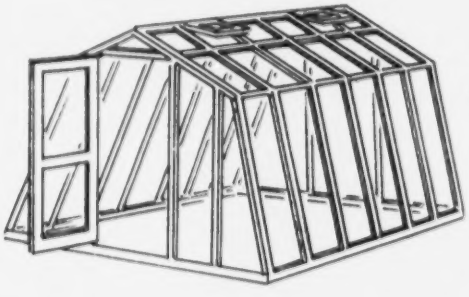


Quonset (hoop) greenhouse





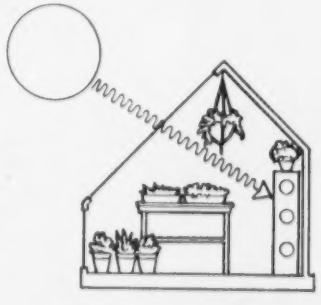
Gothic arch greenhouse



Dutch style greenhouse

Solar—Aren't They All?

There is a distinction between greenhouses that are heated strictly or largely by the sun and those that receive supplemental heat. In all but the deep South of the United States, the sun is never directly overhead, but moves across the southern sky from east to west. Its arc is higher in the summer and at a lower angle in the winter. One builds a "solar" greenhouse to maximize light and heat in an attempt to heat with the same light used to grow.



Since the sun doesn't shine from the north, most solar greenhouses have a north wall made of a dark, heat-absorbing material such as stone or black barrels filled with water, to store daytime heat for nighttime use. (Raised soil-filled beds also contribute to heat storage.) These substances, which have a high "thermal mass," absorb the sun's energy during the day and slowly release the heat during the night. The east and west walls are often half-solid since sunlight will hit them for only part of the day. The southern side which always faces the sun, is fully glazed (see page 7) and is angled so it's perpendicular to the sun's rays during the seasons of maximum greenhouse use. Solar greenhouses often have two layers of glazing (polyethylene, twin-walled polycarbonate sheets, etc.) with an air space in between to insulate and reduce the rate of heat loss at night, while allowing light to pass through. If you're interested in energy efficiency, you might want to explore solar or partially solar greenhouse options.

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Cost

The cost of building or buying a greenhouse varies tremendously. It could range from several hundred dollars for an unheated polyethylene hoop house (like the School Greenhouse Kit sold by the National Gardening Association) to $20,000 or more for a year-round, automated, heated structure. Those in northern climates may want to consider the cost of heating, while schools in southern climates need to be more concerned with ventilating and cooling.

Garnering Financial Support

If you're constructing or refurbishing a greenhouse, you'll need significant funds for site work, consultants, construction, interior supplies, and so on. One school received construction start-up money through the federally funded Title IV Safe and Drug-Free Schools and Communities Act. School and community representatives designed a program to help at-risk students work together to create and manage a small greenhouse business. Others have funded greenhouse projects through local foundation grants. To find funds to launch or provide long-term support for a greenhouse project, consider approaching some of the following sources:

- Community development block grants (contact the mayor's office for information)
- Community foundations
- Public school foundations
- Local corporations
- Service clubs
- Parent/teacher organizations

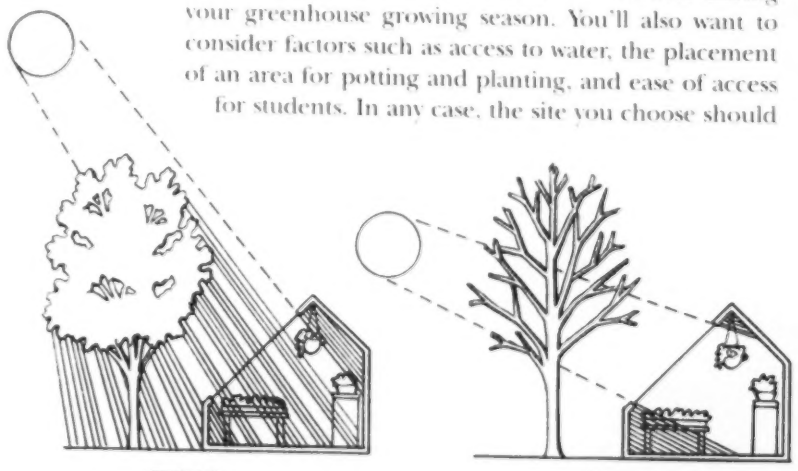
The cost of materials for the actual structure — frame, glazing, doors, and vents — is only part of the equation. A greenhouse structure itself, in fact, may account for only 40 percent of the ultimate budget for the entire project. Other significant expenses to account for include: site preparation, foundation, and accessories (fans, benches, trays, potting soil, fertilizers, watering equipment, shading, and so on). Depending on your location and the type of structure you build, you may need to factor in costs of supplying electricity, heat, and water. If you don't have anyone available to maintain the greenhouse during weekends and vacations, you may need to automate such functions as ventilation. Greenhouse coverings can last up to 20 years or more, or as little as 1 year, so you may need to factor in the cost of reglazing. Talk with experts about these issues early on. The size will, of course, also affect the cost. Do you plan to use it with entire classes or just small groups? A 12- by 30-foot greenhouse might accommodate 240 students yearly, depending on how you use it. Some teachers report comfortably using a 12- by 16-foot model to hold a class of twenty students at one time.

When shopping for a greenhouse, always ask for written quotations, including shipping costs, for basic materials and accessories. Prepare a budget, and be sure your funding is in place before breaking ground.

Location

Whether your greenhouse will be attached or freestanding, it's important to consider what location will give you the most sunlight during the times you will use it, which for most schools are fall and spring. (If you can maintain a minimum temperature of 55 to 60 degrees F at night, you can keep the greenhouse going through the winter.) A greenhouse that's attached to a building above 40 degrees north latitude should have an east/west orientation with the glazed area facing south to provide optimum winter sunlight. Greenhouses located below 40 degrees north latitude can have a north/south orientation to take advantage of eastern or western exposures.

As a general rule of thumb, you should locate a freestanding greenhouse no closer than a distance of two and a half times the height of any wall or other object that might block sunlight. Also assess the role trees will play in your proposed site. There may be a deciduous tree nearby that could provide some needed cooling shade in the summer, but be leafless during your greenhouse growing season. You'll also want to consider factors such as access to water, the placement of an area for potting and planting, and ease of access for students. In any case, the site you choose should



summer winter

Challenge Activity: Shadows and Light

Invite students to explore how objects' shadows change through the day and year. Have them use popsicle sticks to mark the path of a tree, flagpole, or other object as it moves across the ground during the day. You can also map the shadow's size and location during different seasons, and prepare overlays showing shifting patterns of light and shadows. Have students consider how the size of shadows is related to the angle of sunlight. How might understanding this relationship help in choosing a greenhouse site?

be well drained and not subject to settling of water or cold air.

Vandalism has been a problem for some schools. Is the proposed site located where it is relatively protected or visible to watchful neighbors during the weekends and summers? (Regularly invite community members for greenhouse visits and events to acquaint them with your project and enlist their support.)

Glazing

The material that covers a greenhouse and through which the sunlight passes is called glazing. There are many types available, each with its advantages and disadvantages. These include glass, acrylic, polycarbonate panels, polyethylene films, and fiberglass. If you're building, buying, or reconstructing a greenhouse, you'll want to talk with experts and manufacturers about the pros, cons, and cost of various materials. As you review your options, be aware of these general considerations.

Light transmission and energy efficiency — The degree to which a glazing allows light energy to enter and prevents the heat from leaving is known as its efficiency. This is affected by thickness, number of layers, and type of material.

Life span — Plastic glazings can last from 1 to more than 20 years, depending on the type and treatment each receives during manufacture.

Special treatments — Some greenhouse glazings are designed to be especially effective at trapping heat. Some are treated so they are antistatic (these attract less dust and prevent condensation from forming on the inside surface). Some glazings diffuse and reflect the incoming light to reduce shadows.

Safety — Some glazings are flammable while others, like glass, are breakable.

Hail resistance — Hail can batter your greenhouse and your hopes, so select a glazing that can withstand an onslaught if severe hail is likely in your region. A rigid glazing would be best under these conditions.

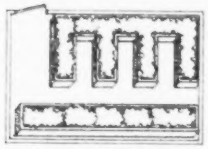
Challenge Activity: Glaze Testers

Have students contact companies and request samples of their glazing materials. Then ask them to design a series of "tests" to evaluate key factors for each product and make recommendations for the greenhouse. They might, for instance, investigate ways to measure light passage, strength, flexibility, heat-trapping characteristics, static resistance, and so on.

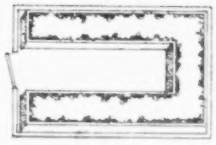
Setting Up the Space

There are a number of factors to consider when setting up the inside of your greenhouse. For instance, how many students would you like to work there at once? Will they work individually or in small groups? Would you like to gather them in one place for large group discussions? What types of projects do you hope to do? Be sure to keep asking: How can we make it safe, comfortable, and user friendly? If practical, invite students to help plan the inside greenhouse setup, or at least personalize some parts of it, perhaps by creating special signs.

A peninsula design for the benches your plants will sit on is often well suited for research, experimental projects, and managing groups. Some schools find that a horseshoe arrangement of growing benches and/or beds provides room for plants around three sides while leaving room in the center for movement and discussion. Rolling, movable benches are efficient and flexible, but can be expensive.



peninsula layout



horseshoe layout

The layout and height of benches for plants and design of the aisles should allow for handicapped access (doors and aisles a minimum of 4 feet wide.) Some of the benches should be at least 2 feet high, to allow for wheelchair seating. You'll also want to consider your students' heights. Either make bench heights adjustable or include several bench heights.

Warning: Shocking News

Be sure that all greenhouse electrical outlets have Ground Fault Circuit Interrupters to protect against electrical shock, and that outlets are placed above where water will be used.

Locating Ongoing Funding

Once you have a greenhouse, you'll have ongoing needs for replacing supplies such as containers, potting mix, and seeds. Many schools have been challenged to think creatively about ways to obtain these supplies without making great demands on tight budgets. In some classes, students write letters or make presentations to managers of garden-supply stores or other garden-related businesses. When you or your students solicit donations, be sure to explain your project and its objectives clearly. Describe how the donation will be recognized (for instance, through a donor recognition sign at the greenhouse entrance). As part of a presentation, remind companies that interested students could grow up to be lifelong customers. Also consider approaching the following groups for donations of new and used gardening materials:

- Botanical gardens
- Local garden clubs
- University or city greenhouses
- Local service clubs
- Community garden groups

Be sure to follow up all donations with thank-you letters. If people know their gift was appreciated and well used, they are more likely to continue giving. Encourage your students to take this on. Heartfelt thank-you letters, children's drawings, and photos of abundant greenhouses with smiling faces are among the most valued ways of saying "thanks" to supporters. Maintain contact by sending them any newspaper clippings or photos that highlight the project, and be sure to mention your donors in any news stories or other publicity.

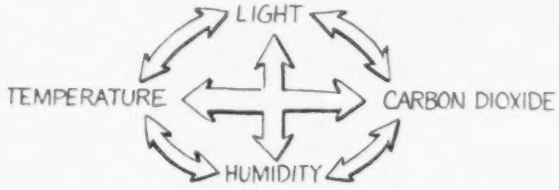
In addition to planting in containers set on benches, you may want to plant some crops directly into soil-filled beds. These are best for simulating habitats, or for growing vegetables to maturity in a garden-like setting. (See page 13 for more about these planting options.)

Also consider how you'll make warm water accessible so students can easily care for plants. If possible, find a location outside the greenhouse for storing soil mixes, fertilizers, and pots, since your growing space is too precious to waste on storage. You'll also need a work area for planting and germinating seeds and for taking and rooting cuttings. Consider creating a spot protected from dampness, in or near the greenhouse, to keep plant- and greenhouse-related reference and fiction books.

Maintaining Proper Conditions

The Greenhouse Environment

While a greenhouse can provide a delightful environment where living things thrive, it is an artificial environment in which you attempt to control as many factors as possible for the benefit of your plant denizens. It helps to recall what actually makes plants grow. Plants convert light into energy (sugar) during photosynthesis. This process requires light, carbon dioxide, "warm" temperatures (between 45 and 85 degrees F), and water. None of these factors operates independently; rather, they affect and are affected by one another, as well as by your greenhouse design.



Your control of these variables will be influenced, in part, by the general type of greenhouse you have, by your local climate, and by the climatic controls you have available in your greenhouse. Exploring and monitoring these variables can become springboards for a range of student investigations.

Greenhouse Climates

The following greenhouse characterizations are based on the temperature that can be maintained, ranging from the least expensive types to build and maintain to the most expensive. Think about which category your greenhouse falls into, and refer to this when reviewing information on what you can grow in your greenhouse. (See page 13 for some growing ideas.)

Cold greenhouse — A cold greenhouse, the least expensive to maintain, is generally a freestanding structure that is heated by the sun only. If you're in a cold winter area, the inside greenhouse temperature may be only 10 degrees or so above the outside temperature. This type of greenhouse is typically used to start or house seedlings in late winter or spring 3 to 4 weeks ahead of outside planting time. It can also be used through the summer and into early fall to grow selected plants. In an area with cold winters, it might be used for overwintering semi-hardy outdoor plants, but more commonly would be shut down.

Cool greenhouse — This type of greenhouse can maintain a minimum temperature of 42 to 45 degrees F. In cold weather areas, such a greenhouse would be heated during winter months. It can be used to overwinter frost-sensitive plants, to start plants 3 to 4 weeks ahead of the cold greenhouse, to raise warm-season crops through the summer, and to grow some cool-weather crops into the fall and winter. It might also be used year-round as a conservatory for desert plants.

Warm greenhouse — This type of greenhouse can maintain a minimum temperature of 55 degrees F, with additional heat during the day and night, as needed, depending on its location. It can be used through the year for a range of growing projects, with heating expenses rising as winter temperatures drop. It provides good conditions for growing vegetables and many annuals to maturity and for conducting a wide range of research projects throughout the school year.

Finding Volunteers

A greenhouse project is a great way to involve parents and other community volunteers in your school. Consider having students send letters to parents explaining the greenhouse project and encouraging them to visit and participate in special activities and events, or requesting support from those parents with relevant skills or expertise. Some schools hold "Open Greenhouse" days or plant sales in which students give tours and presentations. Parents who garden may be flattered by an invitation to talk to classes or lead an activity in the greenhouse. A school newsletter that highlights how the greenhouse is being used can keep parents informed.

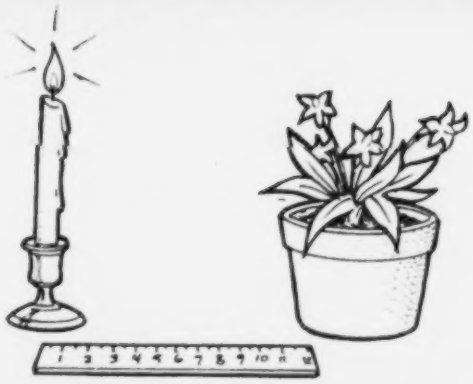
The greenhouse project might also attract a variety of other volunteers who have the expertise to diagnose a specific growing problem, conduct a session with your students, or help conduct teacher inservice workshops. Consider seeking volunteers through such groups as local garden clubs, botanical gardens, or the Master Gardeners' or 4-H program of your local county Cooperative Extension Service.

Hot greenhouse — This type of greenhouse, the most expensive to maintain, sustains a minimum temperature of 65 degrees F with additional heat throughout the year. While too warm for many vegetable plants, it can be used for raising subtropical and tropical plants.

Light

Light provides the energy necessary for plants to produce food through photosynthesis. Without it, plants couldn't make food, and life as we know it would cease to exist. Although it is a factor over which you have relatively little control in your greenhouse, it's helpful to understand a bit about plant light needs. This understanding not only helps you nurture plants, but provides a foundation for a wide range of student investigations.

Plants require certain quantities of light for proper growth. This is often measured in **footcandles**. A footcandle equals the amount (intensity) of light produced in a completely dark space by one candle shining on a white surface that is 1 square foot in size and 1 foot from the candle. Different plants have different light requirements. Most vegetable plants need at least 1,000 footcandles, for instance, while houseplants typically can get by with less. (Many of our houseplants originated on shady rainforest floors, so are adapted to low light levels.) Taller plants tend to require more light than small, bushy ones. Five hundred footcandles is average office light, and outdoor light at noon on a sunny day might be as bright as 10,000 footcandles. Your students can use a camera to explore and experiment with light intensity in different parts of your greenhouse and other environments, as described below in the activity, Measuring Light Intensity.



Unless your greenhouse is close to the equator, the amount and intensity of light your plants get will change as the year progresses. Daylight is the least available during the winter months, and increases toward spring. The increased solar radiation in the spring means more heat. When the days are longer than the nights (after March 21) it is prime time for growing seedlings for outdoor gardens. The summer season is characterized by long days and short nights. Sunlight is so intense that greenhouses often require shading to prevent overheating. Greenhouse tomatoes, cucumbers, and peppers will thrive. After the

Challenge Activity: Measuring Light Intensity

Your students can use a light meter in a manual camera to roughly measure light intensity in footcandles in different parts of your greenhouse. Here's how. First, set the film speed at ASA 200 and the shutter speed at 1/125 second. Aim the camera at a white sheet of paper in the greenhouse. Get close enough so the meter records only the light reflected from the paper (be careful not to create shadows). Focus on the paper and adjust the f-stop until a correct exposure shows in the light meter of the camera. F-stops will equal approximate footcandles as follows:

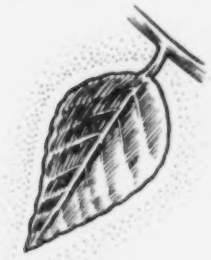
F-STOP	FOOTCANDLES
2.8	32
4.0	64
5.6	125
8.0	250
11	500
16	1,000
22	2,000

Challenge Activity: Seasonal Sun

Challenge older students to explore the sun's seasonal movements by determining the average height of the sun at noon in each of the school year seasons. Establish a viewing spot where observers can stand each time. Let the students decide how to record the path of the sun; for example, "it is 3 index cards above the tree at noon in September and 2 index cards above the tree in November." If you have a large window on a south-facing side of the school, students can mark the path of the sun for a day using adhesive dots, every 2 hours or so. This will establish an arched path across the window. Repeat this once each season using red dots for a "fall sun," another color for a "winter sun," and so on, then comparing where the paths fall. It is important to establish a viewing spot that is used each time by observers of roughly the same height so the spots remain fairly accurate. Warn students never to look directly at the sun!

Carbon Dioxide: Plants' Breath of Life

Carbon dioxide (CO_2) is essential to the process of photosynthesis. If it's scarce, plant growth slows. If your greenhouse air is stagnant, plants can deplete the carbon dioxide in the layer surrounding the leaves, even though there may be plenty in the rest of the greenhouse. Keeping the air moving, via vents or fans, is important for providing necessary CO_2 to plants. Some home and school greenhouse growers have tried increasing CO_2 by composting right in the greenhouse, since the composting process produces carbon dioxide as well as heat. Consider challenging your students to invent other ways of providing CO_2 (e.g., human breath or dry ice!) and experiment to examine its effects on plant growth.



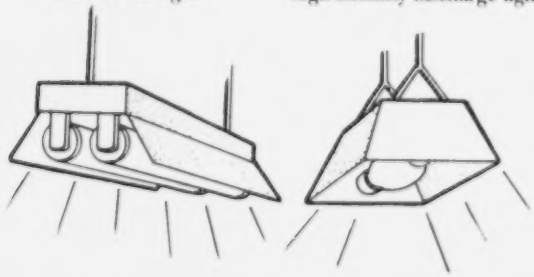
autumnal equinox (September 21), the nights become longer than the days. Although the light intensity wanes, it is strong enough to extend some warm-weather crops or begin a second crop of spring vegetables.

If you notice slow growth, yellowing lower leaves, and stems that are spindly and/or bending dramatically toward the light (phototropism), your plants may not be getting enough light. Make sure plants are not overcrowded and competing for available light. You and your students might also experiment with increasing light by painting interior surfaces white to reflect light to plants. You can also take advantage of different light levels and plant preferences by having students identify areas in the greenhouse that get more or less light, then locating sun-loving and shade-loving plants accordingly.

In geographic areas with chronic low light or long winters, you can use fluorescent or other plant growth lights to supplement natural sunlight. They are particularly useful for getting seedlings off to a good start. High-intensity discharge lamps such as high-pressure sodium or metal halide are expensive but efficient.

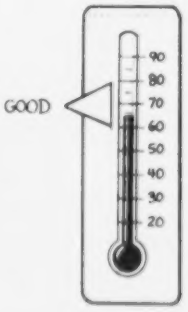
fluorescent light

high-intensity discharge light



Temperature

Plant growth requires heat. Temperature determines plants' speed in taking up water and nutrients, their rate of photosynthesis, and, in turn, their growth. Maintaining a comfortable air temperature for your plants can be a challenge in both warm and cold months. Generally, 50 to 60 degrees F is the ideal low temperature for greenhouse plants, while 85 degrees F is the optimum high, although plants vary in their preferences. Most will experience slow growth below this range and severe stress above it. A useful rule of thumb is that if you're growing tropical natives or food plants of which you eat the fruits (e.g., tomatoes), they can probably withstand higher temperatures. If you're growing plants native to more temperate climates, or ones of which you eat the leaves or roots (e.g., lettuce), they probably can't tolerate high temperatures. Plants generally do best with a 10 to 15 degree drop between day and night temperatures.



Soil temperature is even more important than air temperature in your greenhouse, particularly if you're growing in beds. When soil temperatures are below 45 degrees F, roots grow more slowly and are less efficient at taking up water and nutrients. Warm soil is particularly important for germinating seeds or rooting cuttings. Sixty-five to 75 degrees F is the temperature range recommended for germinating most types of seeds. Have students use a special soil thermometer (available at garden centers or through supply catalogs) to monitor soil temperatures, and consider experimenting with growth rates of seedlings in warmed and unwarmed soils. You can supply bottom heat for containers by purchasing special soil heating cables or mats. Be sure to read the safety precautions carefully, and never try to adapt an electric blanket or heating pad for greenhouse use!

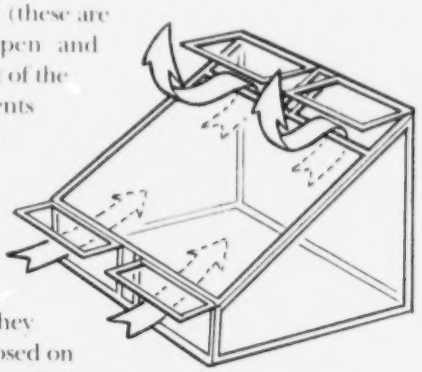
Cooling

To maintain comfortable greenhouse temperatures, at times you may need to keep some light (and resulting heat) out of the greenhouse. Overheating problems are actually more common than underheating problems in

greenhouses. Even in the north, late spring temperatures of 110 degrees F have been recorded inside a greenhouse on a sunny day.

You can use various methods to block some of the sun's rays. These include hanging commercial shade-cloth, typically made of spun or mesh vinyls, from the outside or inside of the greenhouse. (It's most effective when used on the outside.) You can also apply water-soluble shading compounds to glazing during late spring to cut down on incoming rays. Rains will wash your greenhouse clean by winter. Remember that if you create shade to cut down on heat, your plants will also receive less light, and may grow more slowly.

Venting is critical both to draw out hot air and to provide air circulation to reduce problems with pests and diseases. Vents can be manual, electric, or solar (these are triggered to open and close by the heat of the sun.) Ideally, vents should be both high and low to allow for proper airflow. They should be well constructed so they can be tightly closed on the coldest days. Exhaust fans placed high in the greenhouse help push hotter (upper) air out, while allowing cooler (lower) air to enter.



Heating

Depending on your location and growing interests, you may need additional heating to supplement the heat trapped in the greenhouse through solar radiation. This adds to your expenses but allows you to extend your season. It's most important to use any supplemental heating you have when the sun sets and the cold outside air begins to rob the greenhouse of its daytime warmth. Forcing hot water through pipes on the inside perimeter is a conventional heating method. Combining a fan with a gas or oil heater or wood stove is another method for circulating warm air through the greenhouse. Be sure that whatever heating system you use is well vented and has a fresh-air intake. Consult reference materials or experts regarding greenhouse heating options.

Challenge Activity: Shady Dealings

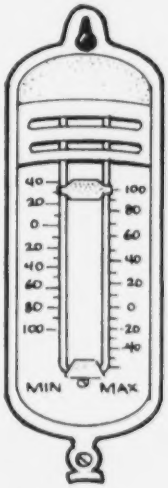
Ask your students to investigate the effect of shade on temperature. Angle a piece of clear plastic or glass toward the sun, and record the temperature underneath. Then shade it with a piece of cloth or netting and repeat the investigation, comparing temperature readings. Try other methods of shading and compare them. Have students speculate on how shading might affect the greenhouse climate, both positively and negatively.

Challenge Activity: Microclimate Search

A greenhouse typically has many mini-environments, or microclimates. This is due to a variety of factors including the following:

- Hot air rises and cool air drops.
- Air next to glazing is cold on winter nights and hot in summer.
- Sunlight enters the greenhouse at different angles through the year.
- Shade cuts down on light intensity.

Invite students to keep records to compare soil and air temperatures throughout the greenhouse. (A maximum/minimum thermometer can be a great teaching tool.) Where is the air warmest in the greenhouse? Coolest? Have them construct a map or chart to illustrate their observations and locate different microclimates within the greenhouse. Then use these environments to your advantage by researching plant needs and grouping plants according to where their needs are best met. (The best environment for a plant is usually determined by its native environment on the planet.)

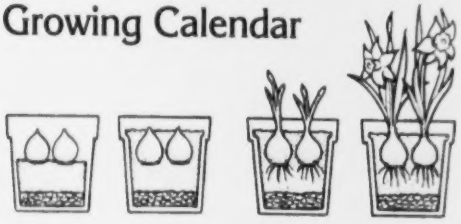


Greenhouse Gardening

If you're using a school greenhouse, you should already have some familiarity with growing plants indoors. There are a wide range of reference materials with information on planting, thinning, transplanting, taking cuttings, scheduling seedling plantings, and so on. *GrowLab: A Complete Guide to Gardening in the Classroom* (see page 24) has comprehensive information on these topics.

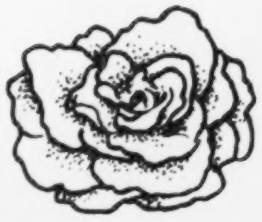
What you choose to grow, and when, depends on your curriculum goals and student interests, climate, and the type of greenhouse you have. Generally speaking, a greenhouse that can remain a minimum of 60 degrees F at night can grow almost any crop year-round as long as you meet other basic needs for light, nutrients, and so on. Most school greenhouses, however, have limitations. (See pages 9 and 10 for a general description of greenhouse climates.) You will be most successful if you match the needs of the plants you grow to your particular greenhouse conditions. It would be quite frustrating, for example, to attempt to meet the needs of a banana tree (which requires bright light and warm temperatures) in a cool northern greenhouse. What you grow also varies seasonally. The following section offers some general suggestions; consult the reference books listed on page 23 for detailed information on growing specific plants.

A Growing Calendar



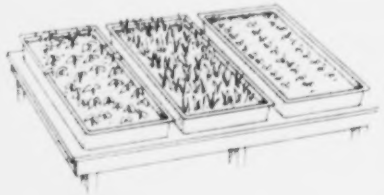
Fall

- Bulbs for forcing.
- Lichen and moss terraria.
- Houseplant cuttings — use plastic domes for humidity and bottom heat if available.
- Seedlings of cool-season crops (Chinese greens, collards, lettuce, herbs) to put in greenhouse beds.
- Warm-season crops (tomatoes, cucumbers, melons) in a heated greenhouse; sow seeds in summer to give plants a head start before light wanes.
- Plants retrieved from the garden — experiment by digging smaller plants of annual flowers, vegetables, and herbs to see what survives the change; check for pests before bringing any garden plants inside.



Winter

- Cool-season crops (Chinese greens, collards, lettuce, spinach, radishes, herbs) if you have a heated greenhouse or live in a warm climate; plant these in fall to establish them before light wanes.
- Forced branches of pussy willows, forsythia, apple blossoms if you have a heated greenhouse or live in a warm climate.
- Tender perennials to overwinter if you have a cold greenhouse.
- Nothing, if you have an unheated greenhouse in a cold climate.



Early Spring

- Seedlings for outdoor gardens.
- Herbs, vegetable plants, flower plants for plant sale.
- Seedlings for warm-season crops (tomatoes, melons, cucumbers) to grow in greenhouse beds through the summer.
- Houseplant cuttings, as above.

Summer

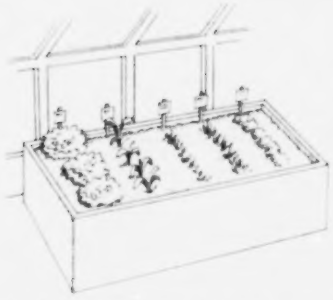
- Warm-season crops (tomatoes, cucumbers, eggplants, melons) in greenhouse beds, particularly in areas with a short growing season.
- Perennials from seed or cuttings.
- Tropical crops (figs, citrus fruits, bananas).

Planting Options

Depending on your annual calendar and project types, you might grow plants in containers on benches, directly in soil-filled garden beds, or in a combination of the two. Some schools use containers set on benches in late winter and early spring for raising seedlings and doing science investigations. Once plants are moved out of the greenhouse, soil-filled beds are used by summer school programs to grow warm-weather crops like tomatoes, cucumbers, or luffa sponges to maturity.

Greenhouse Bed Gardening

Soil-filled greenhouse beds, near ground level or raised to 24 inches or so, can be nice for simulated habitat plantings or for growing vegetables to maturity in a garden-like context. Since beds (particularly raised ones)

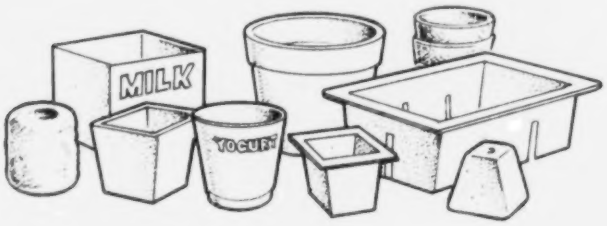


typically contain more soil than do containers, they promote good root growth. The soil also provides thermal mass that retains some of the heat captured during the day. One disadvantage of using beds is that if you do have a problem with soil-borne fungi or other pests, you may have to dump an entire batch of soil to remedy the problem.

You can construct greenhouse beds of wood, bricks, stone, or recycled materials. Don't use pressure-treated wood or most wood treatments, since they often contain substances that can harm plants. Use either untreated hardwood or wood treated with a plant-safe preservative containing copper napthenate (like Cuprinol.) If the beds will be accessible only from one side, build them no wider than 2 1/2 feet. They can be somewhat larger if students will be accessing them from two sides. Greenhouse beds require drainage, so be sure to get advice from experts and include that in your plans.

Container Gardening

If you're growing in containers on benches, then conventional plant pots or recycled materials like cardboard milk cartons or yogurt containers will do the job, as long as you put holes in the bottom for drainage. Unglazed clay pots are good because they're porous (allowing air in and keeping excess moisture out), but are heavy and breakable. Plastic pots, on the other hand, are lighter and easy to clean, but can be more easily overwatered. Have students experiment with a range of container types. Students' written requests to parents and other teachers will likely turn up a variety of donated containers.



Clean containers well to avoid pest and disease problems. Although the most effective way is by soaking them for 1 hour in a solution of 1 part chlorine bleach to 9 parts water, you can usually get away with warm soapy water. Be sure that the container size is appropriate for the plant you're growing. A vegetable plant in a pot that's too small for it will be stressed and susceptible to attack by disease organisms and pests. On the other hand, a plant in a pot that's too large will also grow poorly, because it may get overwatered. If a plant becomes root-bound (the roots appear at the bottom through the drainage holes), move it to a pot 1 or 2 inches larger in diameter. For more information on types and sizes of planting containers, see *GrowLab: A Complete Guide to Gardening in the Classroom* (see page 24 of this guide).

Growing Media

Outdoors, soil stores and releases nutrients, and provides plant support and passages for air and water. It contains living things like bacteria, mites, and worms, as well as nonliving substances such as small particles of sand and clay. Greenhouse soils need to be lighter than garden soils, because frequent watering tends to pack soil down. Many greenhouse growers use soil-based or soilless mixes that have been heat-sterilized so they contain no living organisms such as fungi, weed seeds, or insects that thrive in an inviting greenhouse environment.

Challenge Activity: Mixed Media

Challenge students to explore the effects of various growing media on plant growth. Have them set up a series of containers with different growing media, then plant the same type and number of seeds in each pot. What do they observe over time? Which medium dries out most quickly? Which one supports faster or better plant growth?

Mixes for Containers

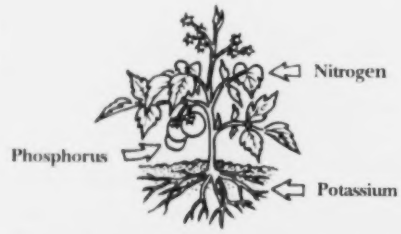
We recommend using a commercial soilless mix (available at garden centers, nurseries, and hardware stores) for starting seedlings, which are particularly susceptible to disease and require a light media that holds moisture well. If you and your students are adventurous, you can make a soilless medium yourselves by mixing 1/3 Canadian peat moss, 1/3 perlite, and 1/3 vermiculite. Although good for starting seeds, these soilless mixes are low on nutrients and tend to dry out quickly. For larger plants, you should find a heavier commercial potting soil that contains some sterilized soil or organic material.

Mixes for Beds

If you're growing in beds, you'll want to provide a soil mix that closely approximates soil found outdoors, but with better drainage. Although some people recommend

Nutritionally Speaking

Plants require certain nutrients in order to thrive and grow. These are not actually food, but chemical elements or minerals that are vital to helping a plant use the sugars (the real food) that it produces during photosynthesis. Nutrients are normally found in soil, in decomposed organic matter such as compost, and in commercial fertilizers. The "macronutrients" — those required in the greatest amount by plants — include nitrogen, phosphorus, and potassium. Micronutrients such as iron, sulfur, and zinc are also required by plants, but in smaller quantities.



Garden soil and organic matter in greenhouse beds provide some nutrients to the crops. You may want to "sidedress" plants with compost or other fertilizer from time to time as you would plants in an outdoor garden.

Container-grown plants require more frequent fertilizing than those grown in greenhouse beds, particularly if you're using a soilless or nearly soilless potting mix.You can fertilize plants in containers with commercial liquid or water-soluble fertilizers, or slow-release pellets. Whether using organic or synthetic fertilizers (you may want to compare different types), look for those containing micronutrients, and follow directions on containers. Because plant needs are so interconnected, plants tend to need more nutrients during the summer when they receive more light and heat, and fewer nutrients in the winter.

keeping garden soil out of greenhouses, real garden soil in a greenhouse bed can help maintain a healthy balance in which "good" microbes and organisms keep problems in check. This is particularly true if you add compost, peat, or other organic matter. To make your own soil for beds, mix 1 part rich soil, 1 part organic material (peat moss, leaf mold, or screened compost), and 1 part drainage material (sand, vermiculite, perlite). You'll also need to check and adjust the pH (to keep it between 6.0 and 6.8) and may want to add other mineral amendments to provide additional nutrients. There are a wide range of opinions on and recipes for greenhouse growing media. Consult references on page 23 for more information. When filling beds, first lay down a few inches of gravel and a few inches of sand on the bottom for drainage, then add 1½ feet or more of your soil mix.

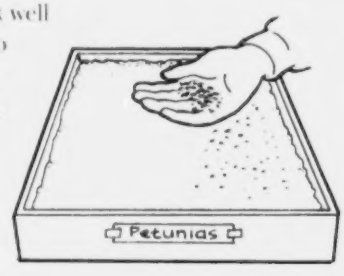
Starting from Seed

You and your students will want to start some seeds in their permanent containers or beds, either because you are raising crops that do not transplant well (such as beans, peas, cucumbers, melons, squash, carrots, beets, or radishes) or because you don't want to take the time to transplant them later on. You may choose to sow other seeds in temporary containers, and later transplant them to larger containers or greenhouse beds. This saves space, allows you to choose only the healthiest seedlings, and involves students in an important and exciting gardening activity.

If you're growing vegetable crops to maturity in the greenhouse, look for designated greenhouse varieties. Such designations indicate the plants may be heat tolerant, resistant to certain diseases, or otherwise adapted to a controlled greenhouse environment. Greenhouse varieties of certain crops, like cucumbers, are specially bred to produce fruits without being pollinated.

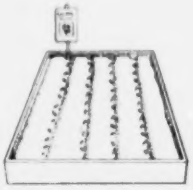
Planting Tips

- Use a disease-free, well-drained soilless mix and clean pots for sowing seeds.
- Moisten the soil mix well and fill containers to within 1 inch of the top before planting.
- Plant seeds at a depth of two to three times their width (unless they need light to germinate). If seeds are very fine, or require light, sprinkle them on the surface and gently pat them into the soil.

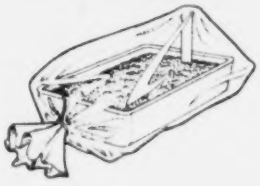


- If sowing seeds directly into their permanent containers, space the correct number of seeds evenly around the container. Because it is unreasonable to expect 100 percent germination, put two seeds in

each planting hole. (See *GrowLab: A Complete Guide to Gardening in the Classroom* for information on correct spacing in containers, referenced on page 24 of this guide.)



- If sowing seeds for later transplanting, space them about 1/4 inch apart in rows 1 to 2 inches apart (unless they are extremely fine, as above).
- Keep soil moist while seeds are germinating, by covering the container gently with a plastic bag or dome.

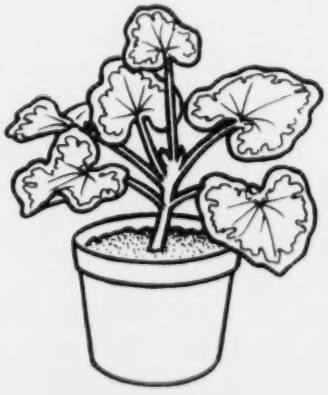


- Keep containers in a warm spot (70 to 75 degrees F), or use heating mats or cables to maintain warmth.
- Once seedlings emerge, immediately put them in the light. If germinating under fluorescent lights, keep lights 1 to 3 inches from the seedlings.
- Don't begin fertilizing until the seedlings have six to eight leaves.
- Thin or transplant seedlings once they have their first true leaves, so they don't compete for resources. (See *GrowLab: A Complete Guide to Gardening in the Classroom* or other reference books on page 23 for detailed information on thinning and transplanting.)

Starting from Cuttings

Propagating plants from parts of other plants is a relatively easy way to increase your collection quickly (perhaps for a plant sale) and to engage students in investigating vegetative propagation. Many common houseplants will root nicely in a greenhouse environment. Taking and rooting stem cuttings from tomatoes can also be fun to try. Depending on the plant, you can take stem, leaf, or plantlet cuttings. Consider taking stem cuttings of some of the following:

Begonia
Coleus
Geranium
Impatiens
Ivy
Philodendron
Tomato
Wandering jew



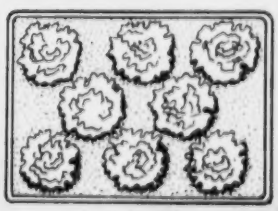
Tips for Stem Cuttings

- Select a healthy, well-watered parent plant and take a 3- to 5-inch cutting from a newer, fast-growing tip.
- Remove all but the top few pairs of leaves.
- Fill a container with moist soilless mix, and poke holes at least 1 inch apart to accommodate cuttings. (You can root multiple cuttings in one container and repot them once they've rooted.)
- Carefully place each cutting in a hole and close up the hole. Some people dip cuttings in a commercial rooting hormone, available in many garden centers, to speed rooting and prevent the stem from rotting. Although many plants will root without the extra hormone, it can provide a nice springboard for student-designed comparisons and experiments.

- Place individual containers in plastic bags propped up with stakes or under plastic domes and seal them to retain moisture, since high humidity is important for rooting.
- Keep them in a warm area in the greenhouse, and check containers occasionally to ensure there is adequate moisture. (There should be some droplets of water on the inside of the bag, but the bag should not be soaking.) If the soil appears too wet, punch a few holes in the bag.
- After a few weeks, tug gently on the cuttings to see if they've rooted. When you feel resistance, they're ready for transplanting. Gently separate them and move them to individual pots.

Arranging Plants in Beds

An efficient way to grow plants in soil-filled beds is to stagger them, as illustrated rather than planting them in rows. Also try to use vertical growing space in beds when possible, by using stakes, vertical strings, or trellises for crops like tomatoes, cucumbers, and peas. This not only uses space efficiently, but promotes better airflow, which reduces disease problems.



Becky Young, a Missouri Botanic Garden educator, suggests having students make individual propagation bags for rooting stem cuttings in the greenhouse. Have them take cuttings, as above, then place them in a resealable plastic bag with a wet paper towel, removing any remaining water so air can circulate around developing roots. Seal the bag tightly, then place it in a warm spot out of direct sunlight. Some teachers even hang them on walls. Once the cutting has rooted, plant it in potting mix, as above. "Invite students to try varying moisture, temperature, or light to see if and how growth is affected," suggests Becky.

If Not Bees, Who?

In nature, flowers are pollinated by insects, wind, birds, bats, and so on. Without natural pollinators in greenhouses, who does the work of moving pollen from the male to the female flower parts, so fertilization and fruit and seed production can occur? Fortunately, many crops that produce edible fruits or seeds have both stamens (male parts) and pistils (female parts) in the same flowers. Pollination occurs easily since the parts are arranged to facilitate pollen transfer. Greenhouse crops such as tomatoes, peppers, and beans are in this category. You can help pollinate them by shaking them gently from time to time. Special European varieties of greenhouse cucumbers are designed to bear fruit without pollination. If you and your students want to try to "play the bees," you can do so with regular garden cucumbers, melons, or squash. See *GrowLab: A Complete Guide to Gardening in the Classroom*, for details (see page 24 of this guide).

Watering

Least understood and often most mismanaged in school greenhouses, is the ongoings hallenge of watering. Water is the solvent that carries minerals from the soil to plants via the roots. A raw material used in photosynthesis, water enters the roots as a liquid and exits the leaves as a vapor as it's transpired. The amount of water plants require is affected by the drainage capacity of the growing medium used, the temperature and light plants receive, the amount of airflow, the stage of plant growth, and the type of plant. Young, actively growing seedlings, for instance, require constant moisture, while a mature cactus needs very little.

Children tend to overwater and drown with kindness. Overwatered plants are just as much at risk as those that are underwatered. (Sometimes overwatered plants wilt as their roots suffocate, leading us to think they need even more water!) Discuss plant needs for just enough water, then have children practice "reading" this need by using a finger to check moisture levels. If the soil feels dry an inch down, it's time to water. Don't necessarily water out of habit or on a schedule, because plant needs can change from day to day and season to season.

Slightly warm (65 to 80 degrees F) water will avoid the shock that cold water produces. Try to water in the morning to minimize evening condensation on leaves, which can lead to diseases, and minimize watering on cool, cloudy days. When watering, be careful not to splash mud, damage seedlings, or get water on fuzzy-leaved plants. Be sure to water thoroughly, until it drains out the

Challenge Activity: Water Wisdom

Large greenhouse operations often determine water needs and use "automatic" watering measures, such as drip irrigation. Give your students some water-related challenges. For instance, ask them to design a simple self-watering system (perhaps with absorbent cloth wicks), a method of warming water before it's used on plants, or a "clue" chart to help one another decide when it's time to water.

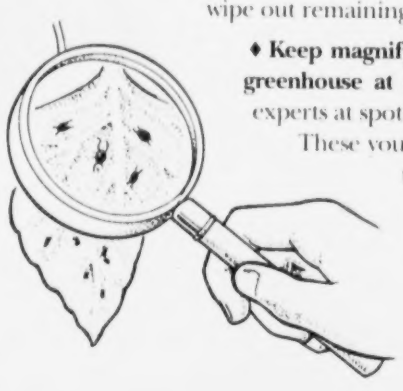
bottom of containers or puddles in a growing bed. Watering too lightly can cause a buildup of fertilizer salts, which can be toxic to plants, and also stimulates shallow, surface roots at the expense of larger roots.

Humidity

Humidity is essentially how "wet" the air is. One can measure relative humidity, using an instrument called a hydrometer, as a percentage of the maximum moisture air can hold at a given temperature and pressure. Hot air holds more water than does cold. Most plants do best with a relative humidity between 45 and 60 percent. High humidity leads to pest and disease problems and causes vapor to condense when warm water-filled air hits a cold window. (This can cut down light, drip on plants, and rot sills.) Low humidity, on the other hand, can dry out plants. Transpiration from plant leaves contributes greatly to greenhouse humidity. To avoid excessive humidity, water early in the day and only when needed, and make sure you have good greenhouse ventilation. If your humidity is too low, you can raise it by periodically wetting down the floor or misting plants. Invite students to use a hydrometer to track humidity daily and to draw correlations between humidity and other factors such as temperature.

Challenge Activity: Pest Sleuths

Have students observe, sketch, and try to categorize and identify the different organisms in your greenhouse. Which pests seem to have which plant preferences? What types of environmental conditions seem to attract different organisms? Invite students to research and investigate the life cycles and needs of common greenhouse pests and beneficial insects, then use this information to invent ways to reduce pest numbers. Find out how commercial growers deal with pest problems. Research and debate the use of chemical versus biological approaches.



Tackling Pests and Diseases

In a greenhouse, you attempt to maintain a microenvironment that may be quite different from the outside environment. There naturally will be attempts by other organisms to colonize the paradise you have created. After all, if you were a whitefly or an aphid, wouldn't you rather spend the winter in a warm, moist, verdant spot than in a hard egg under a frozen log? If and when you deal with pest problems, take heart in the fact that plants often survive pest and disease attacks and that such events can lend another dimension to your students' investigations and understanding of life science concepts.

Prevention: The Best Medicine

Healthy plants are the best defense against greenhouse pest and disease problems. Here are some tips to help you prevent problems before they start:

♦ **Keep it clean!** Promptly dispose of all trash, plant parts, diseased plants, and plants past their prime so they won't harbor problems. If you receive plants, inspect them carefully and quarantine the newcomers elsewhere for a few weeks before putting them in the greenhouse. Have children wash hands with soap and water after handling diseased plants. Make sure your hose doesn't become a disease spreader; keep it from direct contact with plants and keep the nozzle off the floor. If possible, avoid tracking soil and mud into the greenhouse. Start with fresh planting media each season. At least once a year (usually in the fall before you start new plants), scrub and rinse the greenhouse interior from top to bottom with a warm disinfectant soap solution. This can eliminate certain fungi, algae, and soil-borne diseases. If your greenhouse is empty during the winter, you may want to do a "freeze out," letting the inside temperature plunge to wipe out remaining pests.

♦ **Keep magnifying glasses and/or hand lenses in the greenhouse at all times.** Your students can become experts at spotting trouble before it gets out of hand. These young sleuths may have some new adventures and ideas for investigations as they scan the leaves for aphids and other fascinating visitors. Be sure they look over the entire plant, particularly on the undersides of leaves.

♦ **Keep air circulating and plants dry.** High humidity (above 70 percent) and stale air encourage many pests and diseases. Good ventilation and even small circulating fans can make a big difference. Avoid watering plant leaves, unless humidity is low, and try not to water in the evening.

♦ **Care well for your plants, giving them the recommended amounts of water, fertilizer, and so on.** A deficit or excess can stress plants and invite problems. High levels of nitrogen from fertilizer, for instance, can attract aphids which, in turn, can spread diseases.

Greenhouse Pests 101

What types of visitors can you expect? Some of the most common greenhouse pests are aphids, whiteflies, and spider mites (descriptions below). If your student sleuths notice plant problems or greenhouse guests, have them first try to identify them (using a greenhouse, houseplant, or insect identification book) to make sure they are, in fact, problems and not beneficial organisms that prey on pests or problems caused by some other type of plant stress. In early stages, your students can hand pick and squash problem pests. For larger infestations, you might try a dilute solution of insecticidal soap sprayed on the entire plant, especially leaf undersides. You can purchase these commercially or use mild dish liquids or soaps like Ivory Liquid at solutions of 3 to 6 tablespoons per gallon of water. If you have a bad infestation, spray every 3 to 5 days, first testing the solution on a small portion of a leaf (since some leaves can be harmed). While soap sprays can be effective with a range of pests, they can also harm the good ones, so use them judiciously. Some schools also report success after carefully experimenting with homemade sprays containing hot pepper, garlic, and other strong substances. A number of greenhouse pests, particularly whiteflies, can be lured to yellow boards or cardboard hung throughout the greenhouse and covered with Tanglefoot, a thin layer of axle grease, or another sticky substance.

You might also want to consider using natural predators or biological controls to discourage populations of certain greenhouse pests. Ladybugs, praying mantises, and other beneficial insects, if properly introduced, can keep pest populations down, and can provide fascinating fuel for investigations. You'll need to research their life cycles, food preferences, environmental needs, and so on, before tackling such a project. (See page 23 for a list of suppliers of beneficial insects.) You might also try luring some local beneficial insects to your greenhouse by growing plants they like, such as nasturtiums, marigolds, carrots, dill, and mint (and leaving vents unscreened.)

Common Greenhouse Pests

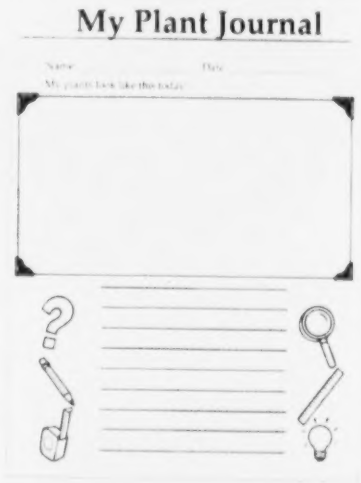
Pest	Description	Control
Aphids	Small, pear-shaped insects with long legs; often pale green to white; may be winged or wingless; secrete a sticky honeydew; found on new buds, rapidly growing tips, under leaves near veins; they suck plant juices, reducing vigor, stunting plants, and transmitting diseases.	Squashing; hard water spray; soap spray; homemade spray; predators (brachonid wasps, certain predatory midges, green lacewings, ladybugs).
Spider mites	Nearly microscopic (less than 1/16 inch) arthropods with four pairs of legs as opposed to an insect's three pairs; create webbing strung between the leaf and stem; damage appears as leaf mottling; thrive in hot dry seasons and prefer foliage plants.	Repeated hard water sprays; predators (predatory mites).
Whiteflies	Tiny, delicate, white-winged insects that feed on a wide range of plants; in large numbers, they'll rise up in a white cloud when disturbed; immature stages look like transparent to opaque white dots on underside of leaves; adults congregate on tips; damage similar to that of aphids.	Soap spray; yellow sticky traps; predators (*Encarsia formosa* wasp).

Nurturing Learners

When you share the joy of discovery with your students, you provide them with an ideal model for learning. You need not be a "greenhouse expert" to maintain a dynamic, productive learning environment. "My students and I have learned most by making mistakes and testing new ideas together," reports high school teacher Mark Wilde of Swanton, VT. View your students' questions as opportunities to inquire and investigate together rather than as a challenge to your own understanding.

How you use the greenhouse with your students depends on your own educational philosophy, your curriculum objectives, and your students' needs and interests. Some teachers adopt a "constructivist" approach by challenging students to establish their own knowledge base through active investigations. The teacher facilitates the process, introduces concepts, and supplies technical vocabulary and resources as needed to support student inquiry. Other educators involve students in more teacher-directed growing projects.

Research suggests that students learn in various ways. Some students prefer a personal approach, learning best when they can discuss their thoughts and work with other people. Others are happiest working by themselves. Some students want to be able to research what other authorities have to say, thriving on using books and articles to get ideas. Some students are "engineers" who must get right in there to invent, test, and mess around with materials. Still other students are happiest when they are pulling parts of a project together and designing reports or displays of their experiences.



Greenhouse projects can support different learning styles and the opportunity for students to appreciate one another's differences. Consider establishing small cooperative groups of two to four students, while still allowing children to work alone for short periods of time. Make reference materials available in your classroom or in the school library. Encourage students to design their own greenhouse experiments and growing projects. Create a climate that allows students to actively share their discoveries with the class, other teachers and students, and parents.

Student Greenhouse Managers

In some school greenhouses there is a "manager," typically an adult who does most of the monitoring, watering, fertilizing, and other greenhouse management work, while students are invited in to do preplanned experiments and projects. It may be educationally valuable to involve students, whenever feasible, at a deeper level — to let them become proficient at various aspects of monitoring, managing, and working in a greenhouse, and designing their own investigations stimulated by their own questions. With suitable support and references, they can assume responsibilities as caretakers and problem solvers. Retired school district horticulturist Bill Horton says: "Never force a student to work in a greenhouse. Allow them to. For some kids it is a chore, while for others it's a welcome opportunity. People, like plants, have different tastes and talents, and all of them deserve respect for who they are."

An important part of successful greenhouse gardening (and a particularly important set of skills for students) is regular monitoring. Keep an air thermometer, soil thermometer, hydrometer (for humidity), maximum-minimum thermometer and record-keeping materials handy. Students will hone skills as they collect weather data and apply the information to managing the greenhouse. Challenge them to discuss how to maintain temperatures between 45 and 75 degrees F, keep the humidity in a comfortable range, or otherwise maintain a plant-friendly environment.

Developing Objectives

In planning greenhouse lessons and projects, it's important to identify what you hope students will gain, including certain skills, knowledge, and attitudes, recognizing that a range of unintended outcomes will also emerge as students explore based on their own interests. Making certain objectives the basis of your planning will help you clarify expectations, bring coherence to the unit, and assess student gains.

The following key concepts and student performance

skills, adapted from the draft 1995 New Standards Project, are some examples of outcomes you might target in a greenhouse lesson or unit.

Student Understanding of Life Science Concepts

- Characteristics of organisms (needs and environments that meet them).
- Life cycles.
- Changes over time.

Student Understanding of Scientific Connections

- Big ideas and unifying concepts (order, change, cause and effect, etc.).
- The designed world (agriculture and technology).
- Science as a human endeavor.

Student Ability to Use Scientific Thinking Skills

- Ask questions about objects, organisms, and events.
- Seek information from reliable sources, including observation and trying things out.
- Recognize a fair test.
- Work individually and in teams to collect and share information and ideas.
- Identify problems, propose and implement solutions.

Greenhouse Activities for Growing Minds

Opportunities for using a greenhouse as a teaching/learning environment are limited only by the imagination. We recommend starting small and simple, with some basic growing projects to build your confidence in managing greenhouse growing and student greenhouse activities, and to build your students' capacity and skills for working and learning in a greenhouse context.

Throughout earlier sections, this guide features ideas for activities to help students investigate key greenhouse concepts related to light, microclimates, growing media, and so on. The book *GrowLab: Activities for Growing Minds*, published by the National Gardening Association, is an excellent source for additional hands-on, minds-on, plant-based greenhouse investigations. It details activities to engage kindergarten through eighth grade students in exploring key life science and environmental concepts. NGA's *Growing Ideas* newsletter also contains a wealth of ideas for plant investigations and thematic growing projects. (See page 24 for more information on these materials.)

Below are a few additional ideas for short-term activities and long-term projects, drawn from our experiences and from discussions with schools in our growing network. These ideas are just the tip of the iceberg. We're eager to hear from more of you who have used greenhouses as living laboratories. Please use the form on page 25 to share your growing experiences with us!

Growing Across the Curriculum

When children work in a greenhouse, their questions naturally lead them in directions that support interdisciplinary learning. Where does this plant grow in the wild? (geography and social studies); Why grow spinach? (health and nutrition); How much money can we make selling these marigolds? (math and economics); Why does this soil mix seem to work better? (science). When feasible, draw on this curiosity as an portunity to use the greenhouse as a centerpiece for multidisciplinary learning experiences.

Plant Businesses

A number of schools use greenhouses to start plants and seedlings for special fund-raising plant sales. These include garden vegetables, flower, and herb seedlings; houseplants from cuttings; and even Easter lilies and poinsettias. Typically, students are responsible for researching specific plant needs, projecting sales, starting and caring for plants, and promoting and staffing the sale. Rather than selling seedlings, some schools plant them to beautify local parks, senior centers, and other community locations. Others raise seedlings, marigolds, herb plants, or houseplants for Mother's Day or other holiday gifts.

Greenhouse Treasure Hunt

Consider creating a greenhouse treasure hunt sheet that invites students to use their observation skills and understanding of plants (and insects) to locate organisms with particular characteristics. For example, Find . . . a plant that looks like it originated in a hot, dry climate; . . . a flower whose smell might attract an insect pollinator; . . . a flower on its way to becoming a fruit; and so on.

Adopt-a-Plant

Invite students to get up close and personal to a particular plant by "adopting" it over a period of time. Offer them regular opportunities to observe, draw, measure,

describe, and learn about their particular plant. How does it change over time? What conditions does it seem to prefer? What questions do you have about your plant? How might you find answers?

Plant Products

Have students set up a display of selected plants and some products that are made from them. For instance, an aloe plant and a bottle of aloe-based lotion, a peanut plant and peanut butter, ryegrass and rye bread, and so on. Consider masking the plant names and inviting other students to tour the display and guess some of the plant identities.

Plant Adaptations

Set up an area with plants that have particular adaptations, such as those adapted to dry climates, tropical environments, and so on. Invite students to observe the plant groups, then write about and/or discuss which adaptations they think help the selected plants survive in their particular environments.

Hydroponics Explorations

The light and warmth of a school greenhouse can provide an ideal context for experimenting with hydroponics, the art and science of growing green plants without using soil. Classrooms in our growing network have used a range of hydroponic setups in greenhouses to raise crops such as lettuce, herbs, flowers, and even tomatoes through the school year. The National Gardening Association's *Exploring Classroom Hydroponics* booklet (see page 21 of this guide) features information on hydroponics basics, setting up classroom systems, and engaging students in soilless growing activities.

Thematic Projects

Thematic growing projects can provide compelling contexts for learning life science concepts, monitoring the greenhouse environment, sparking student questions and investigations, and tying in subjects across the curriculum. Some examples follow. Back issues of the *Growing Ideas* newsletter (see page 24) detail how to bring some of these ideas to life.

- Desert garden
- Bulb garden
- Simulated rainforest
- Salad garden or pizza garden
- Economic crops garden (wheat, soy beans, rye)
- Southern crops garden (cotton, peanuts, collards)
- Herb garden
- Butterfly garden
- Sensory garden (colors, textures, aromas)
- Dye plant garden
- Native American Garden

Resources and Supplies

Organizations

Cooperative Extension Service

This government network provides gardeners with a wealth of information and advice. It also supplies helpful gardening publications free or at a reasonable price. Many offices have school programs and/or a network of Master Gardener volunteers. To contact your local Extension Service office, look under "Cooperative Extension" or your county name in the phone book.

The Hobby Greenhouse Association, 8 Glen Terra, Bedford, MA 01730-2048.

Publishes a newsletter and quarterly magazine for home greenhouse owners. Membership is $12 per year.

National Gardening Association, Education Department, 180 Flynn Ave., Burlington, VT 05401. Phone: 800-LETS-GRO (800-538-7476).

The NGA developed GrowLab — an indoor, garden-based science program for kindergarten through eighth grade that features indoor gardening equipment and supplies, inquiry-based curriculum materials, and the *Growing Ideas* teachers' newsletter. Its *Growing Ideas* catalog offers a range of resources for plant- and garden-based learning including an affordable 12- by 16-foot school greenhouse kit. (See page 24 of this booklet.)

Recommended Resource Books

Note: Some of these books are out of print, but may be available in your local library. We've indicated those that we know to be out of print.

Crockett's Indoor Garden, by James Crockett, 1978, Little Brown & Co., New York, NY.

Exploring Classroom Hydroponics, by the National Gardening Association, 1995, Burlington, VT.

Gardening Under Cover: A Northwest Guide to Solar Greenhouses, Cold Frames, and Cloches, by William Head, 1989, Sasquatch Books, Seattle, WA.

Greenhouse Gardener's Companion, by Shane Smith, 1992, Fulcrum Publishing, Golden, CO.

Greenhouse Gardening, by Miranda Smith, 1985, Rodale Press, Emmaus, PA. (Out of print.)

Greenhouses: Planning, Installing and Using Greenhouses, by Ortho Books, 1991, San Ramon, CA.

GrowLab: Activities for Growing Minds, by the National Gardening Association, 1990, Burlington, VT.

GrowLab: A Complete Guide to Gardening in the Classroom, by the National Gardening Association, 1990, Burlington, VT.

Secrets of Plant Propagation, by Lewis Hill, 1987, Storey Communications, Inc., Pownal, VT.

The Complete Greenhouse Book, by Peter Clegg, 1978, Garden Way Publishing, Charlotte, VT. (Out of print.)

The New Seed Starter's Handbook, Nancy Bubel, 1988, Rodale Press, Emmaus, PA.

Greenhouse Equipment and Supplies

A.M. Leonard, Inc., 6665 Spiker Rd., Piqua, OH 45456, Phone: 800-543-8955.

Charley's Greenhouse Supply, 1569 Memorial Hwy., Mount Vernon, VA 98273, Phone: 800-322-4707.

Crop King, Inc., P.O. Box 310, Medina, OH 44258, Phone: 216-725-5656.

Gardener's Supply Company, 128 Intervale Rd., Burlington, VT 05401-2804, Phone: 802-863-1700.

Griffin Greenhouse and Nursery Supplies, 4 Airport Park Blvd., Latham, NY 12110-3500, Phone: 518-786-3500.

Hydro-Gardens, Inc., P.O. Box 25845, Colorado Springs, CO 80936, Phone: 800-634-6362.

Mellingers, 2350 Range Rd., North Lima, OH 44452-9731, Phone: 216-549-9861.

National Gardening Association, 180 Flynn Ave., Burlington, VT 05401, Phone: 800-538-7476.

Vegetable Factory, P.O. Box 1353, Stamford, CT 06904-1353, Phone: 203-324-0010.

Beneficial Insects

Arbico, P.O. Box 4247 CRB, Tucson, AZ 85738-1247, Phone: 800-827-2847.

Gardens Alive! 5100 Schenley Place, Lawrenceburg, IN 47025, Phone: 812-537-8651.

Nature's Control, P.O. Box 35, Medford, OR 97501, Phone: 503-899-8318.

Rincon-Vitova Insectaries, Inc., P.O. Box 1555, Ventura, CA 93002, Phone: 805-643-5407.

More Growing Resources from the National Gardening Association

The National Gardening Association's education programs include instructional materials and equipment and a national network of educators, community partners, and professional developers exchanging ideas that help young minds grow.

GrowLab Garden-Based Science Program

In thousands of classrooms nationally, teachers use our GrowLab indoor garden laboratory and kindergarten through eighth grade curriculum materials to help students think and act like scientists, develop environmental responsibility, and explore subjects across the curriculum. GrowLab's inquiry-based teaching approach encourages students to use their own questions and observations as springboards for learning. GrowLab includes indoor gardening equipment, curriculum resource books (*Activities for Growing Minds* and *A Complete Guide to Gardening in the Classroom*), posters, teacher training videos, and a *Growing Ideas* newsletter that's a continuing source of inspiration for educators.

Growing Science Inquiry

Through our Growing Science Inquiry program, we provide workshops, materials, and support to local leadership teams of teachers and horticultural educators. These professionals become local resources for teaching colleagues who want to incorporate an inquiry-based approach to teaching with plants.

Partnerships for Professional Growth

Through our national database network, we can help you find "partners" in your area, such as botanic garden staff or other teachers who can help you get started with a garden-based initiative, or we can locate consultants who can conduct GrowLab/Growing Science Inquiry workshops.

If you provide workshops or otherwise help classroom teachers integrate plants and gardens into the curriculum, our *Growing Partnerships: GrowLab Professional Development Update* will alert you to effective strategies for supporting teachers.

Youth Garden Grants Program

Through our Youth Garden Grants Program, we annually award grants of gardening equipment and supplies valued at more than $500 to each of 300 exemplary new or existing youth gardening programs. Grant recipients are selected based on need, the strength of their project plan, and the existence of community support. Applications are available each summer for a November deadline.

For More Information . . .

Write, call, fax, or e-mail our education department to request free copies of:

- 1995/96 *Growing Ideas* catalog of instructional resources including:
  - GrowLab Program materials: GrowLab Indoor Gardens, *Activities for Growing Minds*, *A Complete Guide to Gardening in the Classroom*, instructional posters, and videos.
  - *Bottle Biology*, *Exploring with Wisconsin Fast Plants*, and other indoor growing resources.
  - Hydroponic equipment.
  - *Exploring Classroom Hydroponics*.
  - Worm kits and instructional materials.
  - Outdoor gardening books and videos.
  - School greenhouse kit.
- *Growing Ideas: A Journal of Garden-Based Learning*, teachers' newsletter.
- *Growing Partnerships: GrowLab Professional Development Update*, newsletter.
- Youth Garden Grants Program information.

National Gardening Association
180 Flynn Ave.
Burlington, VT 05401
Phone: 800-538-7476
Fax: 802-863-5962
E-mail: nga@together.org

Share Your Greenhouse Experiences with Us

We're eager to hear about your school greenhouse experiences and to share them with other educators through our *Growing Ideas* newsletter and future revisions of this booklet. Please photocopy this page and use it to briefly describe how your school has obtained, funded, and/or used a greenhouse to enrich learning. What are some of your challenges? your successes? your concerns and questions for other schools? **Return to: Eve Pranis, National Gardening Association, 180 Flynn Ave., Burlington, VT 05401. Fax: 802-863-5962. E-mail: eve.pranis@together.org.**

Name | Title | Grade

School/Organization | Street

City | State | Zip

Phone | E-mail Address

Above address location is: ❑ home ❑ work

NATIONAL GARDENING ASSOCIATION